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FIBER-OPTIC-BASED CONTROLS

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The challenge of those involved in control-system hardware development is to accommodate an ever-increasing complexity in aircraft control, while limiting the size and weight of the components and improving system reliability. A technology that displays promise towards this end is the area of fiber optics. The primary advantages of employing optical fibers, passive optical sensors, and optically controlled actuators over conventional control systems are greater immunity from electromagnetic effects, weight and volume reduction, non-radiating characteristics, superior bandwidth capabilities, and freedom from short circuits and sparking contacts. Since 1975, NASA Lewis has been performing in-house, contract, and grant research in fiber-optic sensors, high-temperature electro-optic switches, and "fly-by-light" control-system architecture. Passive optical sensor development is an essential yet challenging area of work and has therefore received much attention during this period.

A major effort to develop and demonstrate fly-by-light control-system technology, known as the fiber-optic control system integration (FOCSI) program, was initiated in 1985. Phase I of FOCSI, a NASA-DOD effort completed in 1986, was aimed at the design of a fiber-optic propulsion/flight control system. Phase II, a NASA-Navy effort currently in progress, will provide the system design, subcomponent and system development, and system ground tests. Phase III, flight demonstration, has also been initiated and will culminate in full FOCSI system flight tests. In addition to a summary of the benefits of fiber optics, the FOCSI program, sensor advances, and future directions in the NASA Lewis program will be discussed.

Fiber-Optic-Based Controls

- Develop the technology neccesary to incorporate fiber-optic-based control systems into advanced aerospace vehicles.
  - Benefits of using fiber optics
  - Fiber-optic control system integration program
  - Fiber-optic sensors research
  - Future directions in fiber-optic-based controls

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Research in fiber-optic-based controls is aimed at developing the technology necessary to incorporate fiber-optic propulsion/flight control systems (fly-by-light) into advanced aircraft. The program includes the development and testing of passive optical sensors and electro-optic components, and the design, development and flight demonstration of a fiber-optic-based control system. An outline of the presentation is included.

Benefits of Fly-By-Light Control Systems

- Immunity from electromagnetic effects
- Weight and volume reduction
- Nonradiating
- High bandwidth
- Freedom from short circuits/sparking contacts

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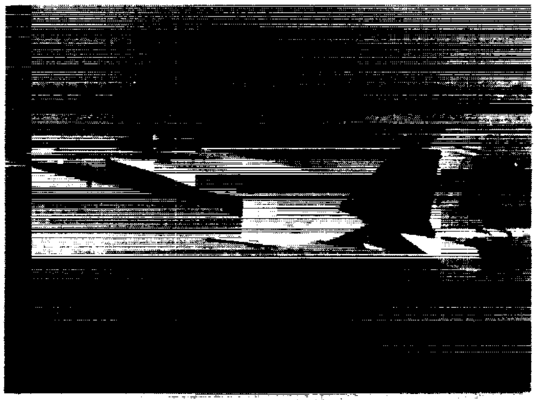
The major benefits of a fly-by-light aircraft control system are outlined. Because optical fibers are dielectric, problems with electromagnetic effects (EME - electromagnetic interference, electromagnetic pulse, and lightning) are eliminated. This, in turn, eliminates the need for shielding and surge-quenching circuits. It is expected that replacing control-system electrical wiring with optical fibers will result in weight and volume savings, as well. Fiber-optic systems are nonradiating, and therefore leave no EM signature. The high bandwidth capability is advantageous for bus lines and offers the potential for all avionics data to be transmitted over a single line. The use of fiber optics also eliminates the threat of fires due to insulation failures or short circuits, which could also cause inadvertent actuation of control hardware.

Fiber Optic Control System Integration (FOCSI)



FOCSI Aircraft

Objective:
NASA–Navy program to develop and demonstrate a fiber optic (fly-by-light) propulsion/flight control system for advanced aircraft.

Program status:

- Contracts for hardware build/environmental testing are on-going with McDonnell-Douglas and General Electric (awarded FY '89/'90).
- Flight tests of individual sensor systems on F-15 (NASA DFRF) to be initiated mid-FY '91.
- Flight tests of full FOCSI system to begin mid-FY'93 on F-18 (NASA DFRF).

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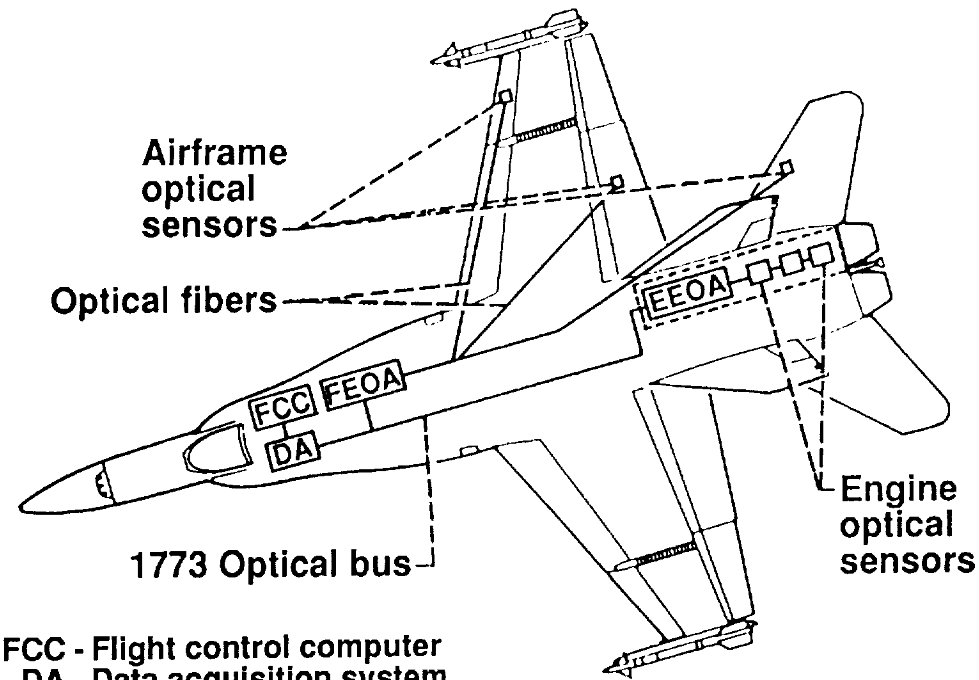
The design, development, and flight demonstration of a fiber-optic integrated propulsion/flight control system for an advanced supersonic fighter is the goal of the joint NASA and Navy FOCSI program. Phase I, to assess current technology and to provide system design options, was completed early in FY '87. Phase II, to design, fabricate, environmentally test, and ground test (engine, iron bird) the FOCSI system was initiated in mid-FY '88. Contracts for the hardware build and environmental testing of the sensor systems and electro-optic architecture were awarded to McDonnell-Douglas in FY '89 and General Electric in FY '90. All ground testing of the propulsion and flight fiber-optic-based systems will be completed early in FY '93. Phase III, flight demonstration, has also been initiated and will result in flight tests of individual sensor systems in FY '91 on an F-15 at NASA DFRF. The program will culminate with full FOCSI system flight tests to begin by mid-FY '93 on an F-18 at NASA DFRF.

Fiber Optic Control System Integration (FOCSI)



FCC - Flight control computer
DA - Data acquisition system
FEOA - Flight electro-optic architecture
EEOA - Engine electro-optic architecture

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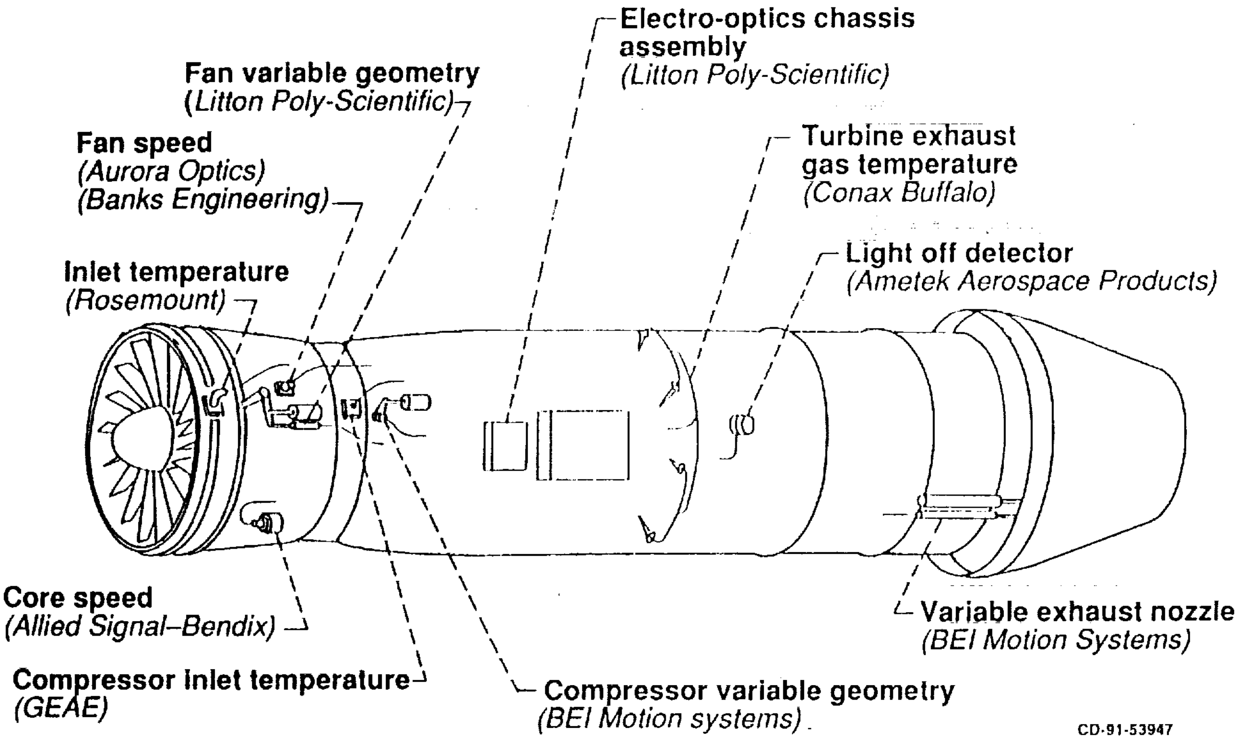
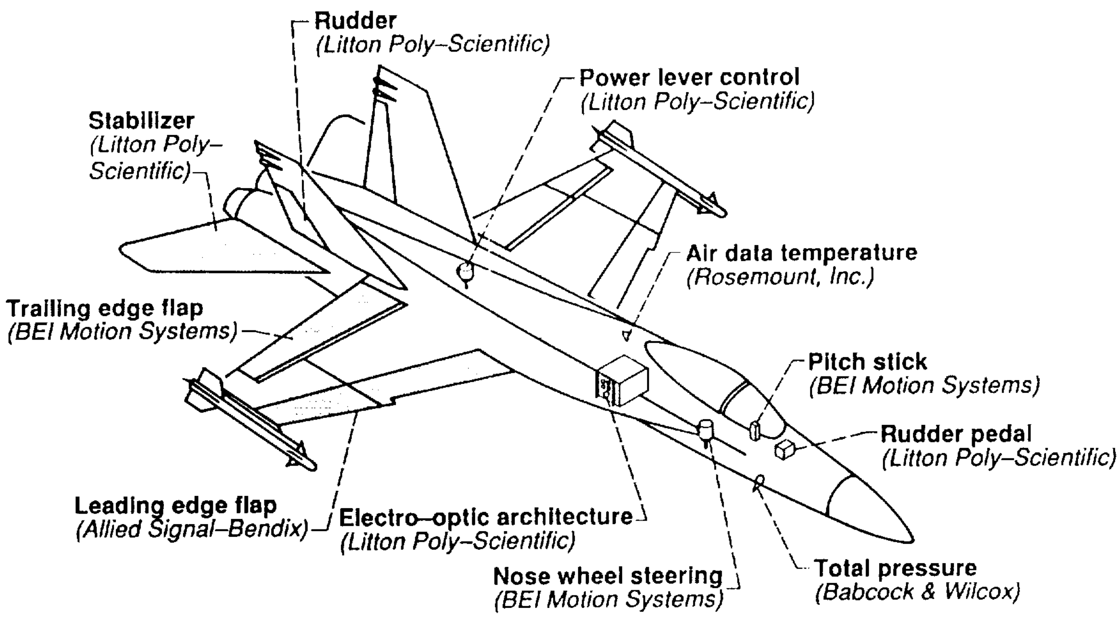
The overall FOCSI system configuration is presented. Propulsion and flight passive optical sensors will be linked to their respective electro-optic architectures (EOA's) via fiber optic cables. The propulsion and flight EOA's will communicate with the data acquisition system using a mil spec 1773 optical data bus. Within the data acquisition system, the conditioned optical sensor signals will be recorded and compared with the corresponding bill-of-material sensor signals.

FOCSI Propulsion System Configuration
Propulsion System Prime–General Electric Aircraft Engines



The full complement of FOCSI propulsion system sensors and the electro-optics chassis assembly (electro-optic architecture - EOA) are shown as they will be mounted on the engine. Subcontractors, selected by General Electric Aircraft Engines, the prime contractor, are listed below each sensor and the EOA. A major of emphasis of this program is to develop a strong vendor base of fiber optic sensor systems and EOA's.

FOSCI Flight System Configuration
Flight System Prime–McDonnell Aircraft Co.



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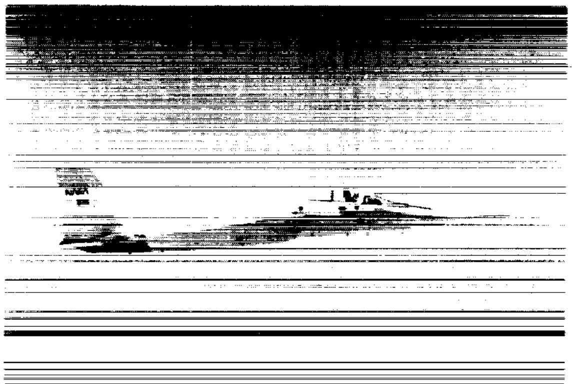
As was previously shown for the propulsion system, the full complement of flight system sensors and the electro-optic architecture are presented. Subcontractors, selected by McDonnell Aircraft Co., the prime contractor, are listed below each sensor and the EOA.

Fiber Optic Sensor System Flight Tests



NASA DFRF F-15 (HIDEC)

Objective:
Lay a solid foundation for achieving FOCSI success by providing information on fiber optic sensor system installation, in-flight operation and maintenance

Status:
- Flight tests (engine bay) of Bendix Faraday speed sensor and Lewis Research Center WDM position encoder to be initiated by mid–FY 91 on F–15 (HIDEC) aircraft.
- Vendors selected for T5 and T1 sensor flight tests (engine penetration) in FY 92 on F–15 (HIDEC) aircraft.
- Lewis Research Center thin film temperature sensor to fly (engine bay) in FY 92 test.

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Prior to installing and flying the full FOCSI system in FY '93, it was felt that select single sensor system flight tests would be worthwhile. This will permit early experience to be gained on sensor system installation, maintenance, and in-flight operation. Planned for this year are tests of a Faraday effect speed sensor developed by Allied Signal-Bendix to read engine compressor speed (N2) through the gearbox power takeoff pad, and a Lewis-John Carroll University wavelength division multiplexed optical position encoder which will measure throttle position (PLA). A second series of flights, slated for FY '92 will test a blackbody turbine discharge temperature sensor (T5) developed by Conax Buffalo and a fluorescence rate-of-decay inlet temperature sensor (T1) developed by Rosemount. Both sensors will penetrate the engine for these tests. Lewis will also supply a novel thin film temperature sensor for engine bay testing. All sensor system flight tests will be performed at NASA DFRF on the F-15 (HIDEC) aircraft. Work with DFRF in fiber optics was initiated in FY '88.

Fiber-Optic Sensors Program Accomplishments

• Tachometer demonstrated on engine	1976
• Position encoder demonstrated on compressor guide vane	1976
• Tip clearance sensor demonstrated on compressor stage	1980
• 800 °C temperature sensor developed	1980
• 1000 °C temperature sensor developed	1983
• Gallium arsenide photoswitch developed (260 °C operation)	1985
• High-temperature pressure sensor developed	1985
• 1700 °C gas temperature sensor developed	1986
• Improved intensity sensor referencing techniques developed	1987
• WDM position encoder demonstrated on engine	1988
• 1900 °C gas temperature sensor demonstrated on engine	1989
• Thin film temperature sensor developed	1990

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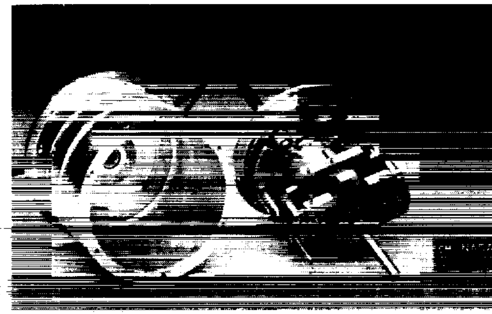
To implement a fiber-optic-based control system requires the development of passive (no electrical connections) optical sensors and optically controlled actuators capable of surviving aircraft environments. NASA Lewis has addressed this critical area of technology since 1975 by developing a wide variety of optical sensors and a high-temperature electro-optic switch through in-house, contract, and grant efforts. Major accomplishments for the fiber optic sensors program are presented for each year since its inception.

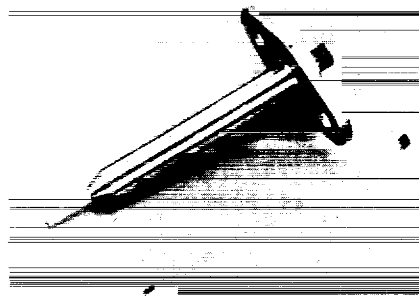
Fiber–Optic Sensors Research

Thin film temperature sensor



WDM position encoder

Intensity sensor referencing techniques



1900 °C blackbody temperature sensor (Conax Buffalo Corp.)

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Current in-house and sponsored research efforts vary from the development of near-term flight prototype control sensor systems through far-term investigation of innovative sensor/sensor system concepts and includes work in

- Flight Prototype aircraft control sensor systems
- On-engine demonstrations of sensor systems
- Laboratory demonstration/testing of new sensor concepts
- Improved sensor referencing /signal processing techniques
- Integrated optics/microfabrication techniques
- Electro-optic component research

The overall goal is to develop miniature, rugged, passive, optical sensor systems which operate reliably in the aerospace environment. Shown above are selected areas of current research, which include (clockwise from top left) a novel thin film temperature sensor, a wavelength division multiplexed optical encoder, a blackbody temperature sensor (SBIR-Conax Buffalo Corp.), and laboratory work to improve optical intensity sensor accuracy and precision.

Future Directions in Fiber-Optic-Based Controls

- Continue efforts aimed at achieving FOCSI objectives.
- Continue development of novel fiber-optic sensor concepts.
- Engine test prototypes of promising fiber-optic sensor systems.
- Continue to sponsor research in the development of electro-optic components.
- Aid in achieving consensus on fiber-optic component specifications for aircraft.

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NASA intends to continue to aggressively pursue all the areas of fiber-optic technology presented. Future directions in the program are presented above. While much work in fiber-optic-based control systems remains, the technology appears well on its way to successful demonstration for aircraft.

One area which deserves more attention is fly-by-light control systems for future generation fighter aircraft and high-speed aircraft such as those flying in sustained supersonic or hypersonic regimes. Such control systems will require fiber-optic components capable of much higher temperature operation than was reported here.

Finally, integrated optics appears to be an area of technology that promises substantial benefits for fly-by-light systems by providing small, rugged, high-temperature, and inexpensive sensors. This is an area in which we intend to increase emphasis in the near future.